

# ADAPTIVE REVERBERATION NULLING USING A TIME REVERSAL MIRROR

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## Abstract

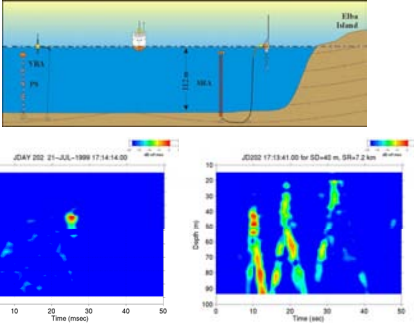
The major problem for active sonar systems operating in shallow water is the detection of target in the presence of severe bottom reverberation. The focusing capability of a time reversal mirror (TRM) suggest two different approaches to this problem. First, a TRM focuses acoustic energy on a target enhancing the target echo while shadowing the boundaries below and above the focus in an acoustic waveguide, thereby reducing reverberation. The resulting echo-to-reverberation enhancement has been demonstrated experimentally in the 3-4 kHz band in shallow water. The second approach is reverberation nulling to enhance target detectability since focusing and nulling are complementary. The idea is to minimize the acoustic energy incident on the corresponding scattering interface by applying an excitation weight vector which is orthogonal to the time-gated reverberation focusing vector. Both numerical simulations and experimental results illustrate the potential of reverberation nulling using a time reversal mirror.

## Problem

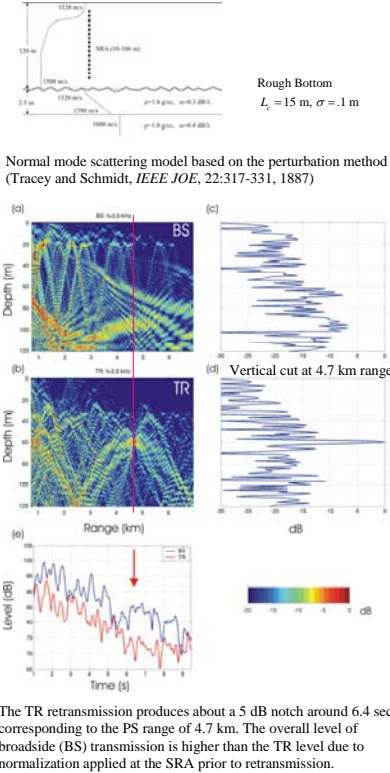
Active sonar systems operating in shallow water is to detect targets in the presence of severe bottom reverberation. The focusing capability of time reversal suggests two different approaches to this problem: echo-to-reverberation enhancement and reverberation nulling.

## Goal

Demonstrate the concept of the two proposed approaches both numerically and experimentally in a shallow water.

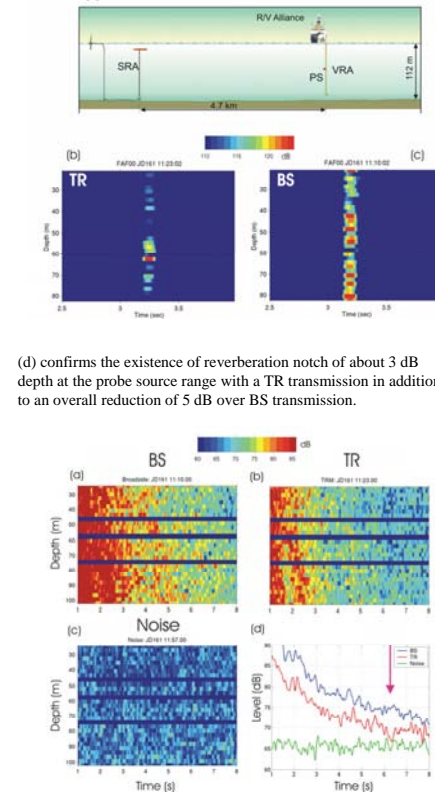


## Reverberation: Numerical Simulation

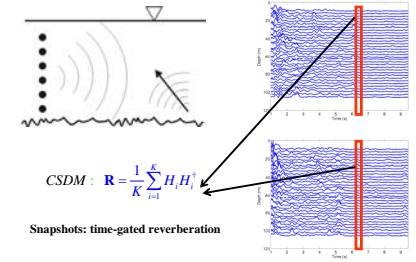


## FAF-00 Reverberation Reduction Experiment

(a) Experimental configuration and (b) enhancement in the ensonification level at the probe source location of 5 dB using time reversal (TR) over BS transmission filling the water column in (c).



## Reverberation Nulling: Numerical Simulation



## Singular Value Decomposition (SVD)

$$\mathbf{R} = \frac{1}{K} \sum_{i=1}^K \mathbf{H}_i \mathbf{H}_i^H = \sum_{j=1}^N \lambda_j \mathbf{U}_j \mathbf{U}_j^H = \underbrace{\sum_{j=1}^d \lambda_j \mathbf{U}_j \mathbf{U}_j^H}_{\text{Signal}} + \underbrace{\sum_{j=d+1}^N \lambda_j \mathbf{U}_j \mathbf{U}_j^H}_{\text{Noise}}$$

$$\mathbf{W}_{\text{focus}} = \text{conj}(\mathbf{U}_1)$$

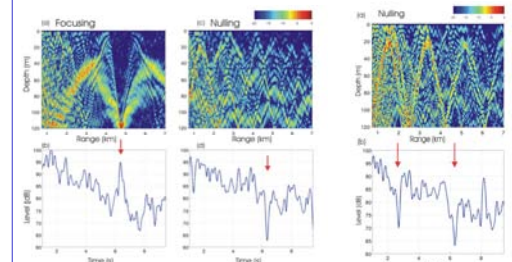
$$\mathbf{W}_{\text{null}} = \text{conj}\left(\sum_{j=10}^N \mathbf{U}_j \mathbf{U}_j^H\right)$$

Distribution of eigenvalues

$\text{TRO} = \text{Conj}(\mathbf{R})$

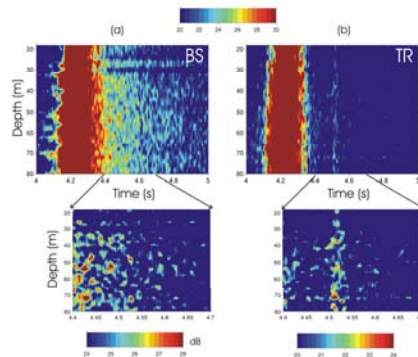
Numerical demonstration of reverberation focusing and nulling

Simultaneous, two points reverberation nulling



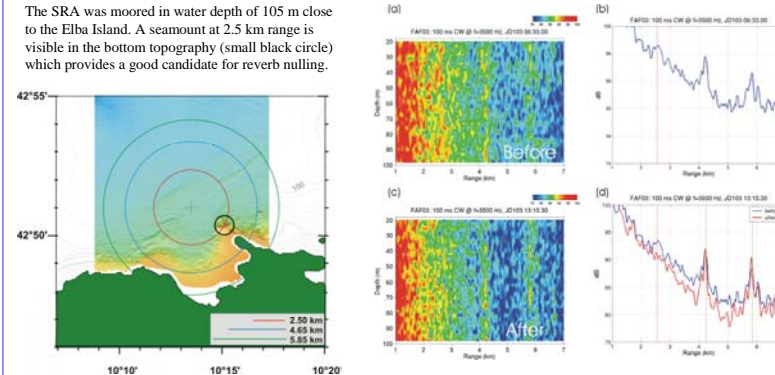
## FAF-00: Echo enhancement experiment (bi-static)

Experimental results including an artificial target show improved target detectability with the time reversal method. An air-filled tube was used as an artificial target. The broad area around 4.2 sec is the direct arrival from the SRA to VRA. An echo is visible around 4.52 sec using time reversal in (b).



## FAF-03 Reverberation Nulling Experiment

The SRA was moored in water depth of 105 m close to the Elba Island. A seamount at 2.5 km range is visible in the bottom topography (small black circle) which provides a good candidate for reverberation nulling.



The upper plots are BS reverberation return (before). The resulting reverberation nulling (after) is superimposed in (d), indicating the reduction of rever level at 2.5 km to the background level by 2 dB. On the other hand, the reverberation return from the interaction with the island has increased at 5.8 km range.

## References

- Kim et al., "Echo-to-reverberation enhancement using a time reversal mirror," *JASA* (in press).
- Song et al., "Environmentally adaptive reverberation nulling using a time reversal mirror," submitted to *JASA*.
- Song et al., "Experimental demonstration of adaptive reverberation nulling using a time reversal mirror," submitted to *JASA*.

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# Adaptive Reverberation Nulling Using a Time Reversal Mirror

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**Abstract** Typically, active sonar systems operate in reverberation-limited ocean environments. The focusing capability of a time reversal mirror (TRM) suggests two different approaches. First, a TRM focuses acoustic energy on a target enhancing the target echo while shadowing the boundaries below and above the focus in a waveguide, thereby reducing reverberation. The resulting echo-to-reverberation enhancement has been demonstrated experimentally using a time reversal mirror in the 3–4-kHz band in shallow water. The second approach is reverberation nulling to enhance target detectability. The idea is to minimize the acoustic energy incident on the corresponding scattering interface by applying an excitation weight vector, which is in the complementary subspace orthogonal to the time-gated reverberation focusing vector. Both numerical simulations and experimental results illustrate the potential of reverberation nulling using a time reversal mirror.